

# **Mars Global Surveyor Ka-Band Frequency Data Analysis**

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# BACKGROUND

- The Mars Global Surveyor Ka-Band Link Experiment (MGS/KaBLE-II) was conducted to evaluate link advantage of Ka-band relative to X-band as a deep space telecommunications link frequency
  - Theoretically Ka-band (32 GHz) provides an 11.6 dB (factor of 14) advantage over X-band (8.4 GHz)
  - In practice, this advantage is reduced to 6 to 8 dB due to increased atmospheric and amplifier noise at Ka-band and DSN antenna imperfections, which are less significant at X-band
  - An analysis of dual MGS Ka-band and X-band carrier signal strength data acquired between 1996 and 1998 demonstrated this link advantage using a 34-m beam waveguide (BWG) ground antenna
- As a byproduct of this link experiment, carrier phase and frequency data were also acquired and analyzed.
  - Individual frequency band residuals and statistics were computed and analyzed
  - Difference frequency residuals were computed and analyzed
    - Non-dispersive contributions cancel out in the  $f_x - f_{Ka}/3.8$  data type leaving charged particles to dominate at long time scales
    - As the higher Ka-band frequency is less susceptible to charged particle effects, it can be used to remove non-dispersive effects from the X-band link allowing charged particle effects at X-band to be probed.
    - Charged particles effects become greater as the spacecraft gets nearer the sun in angle.
  - Individual band spacecraft transmitted USO frequencies were estimated and compared. These frequencies were also compared with independent Radio Science USO frequency estimates

# MGS/KaBLINK-II Spacecraft Configuration

The Mars Global Surveyor (MGS) Spacecraft Carries an Experimental Ka-band (32 GHz) Telecommunications Link in addition to the primary X-band (8.4 GHz) downlink.

The Ka/X Signals are simultaneously transmitted from a 1.5-meter High-Gain Antenna (HGA) on MGS and are received by a 34-meter R&D beam-waveguide antenna (BWG) located in NASA's Goldstone DSN complex.

The two signals have been regularly tracked between December 1996 and December 1998.

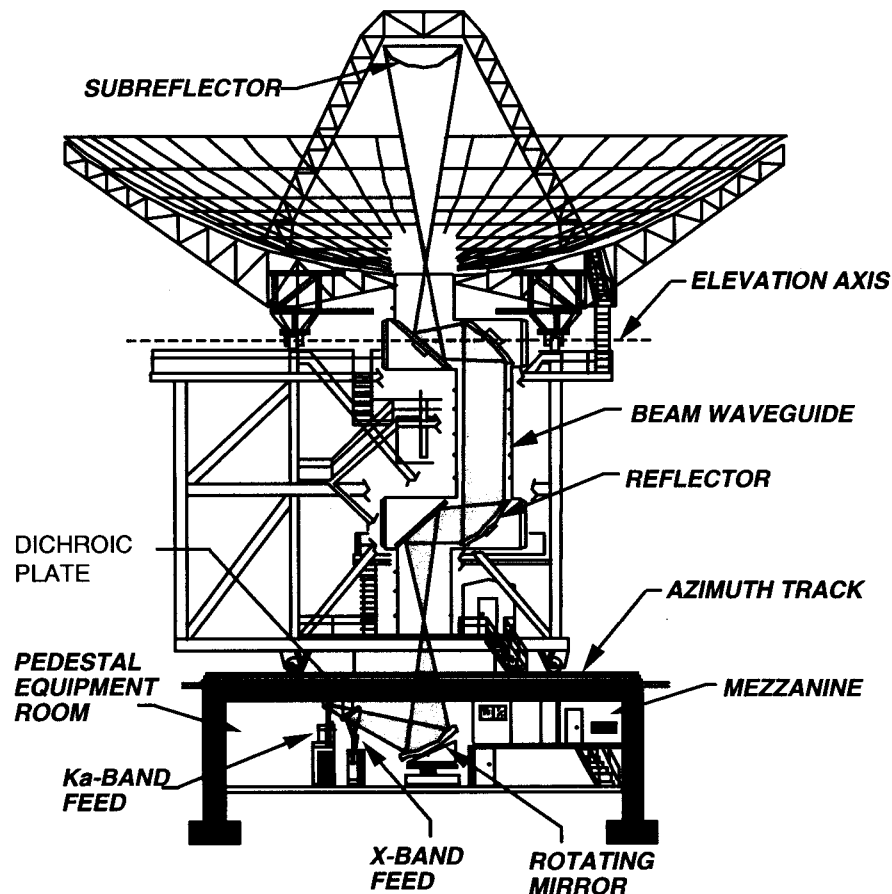
MGS Ka-band downlink frequency can be configured in several modes.

- Can be purely coherent with X-band downlink
- Can be a hybrid combination of USO and VCO

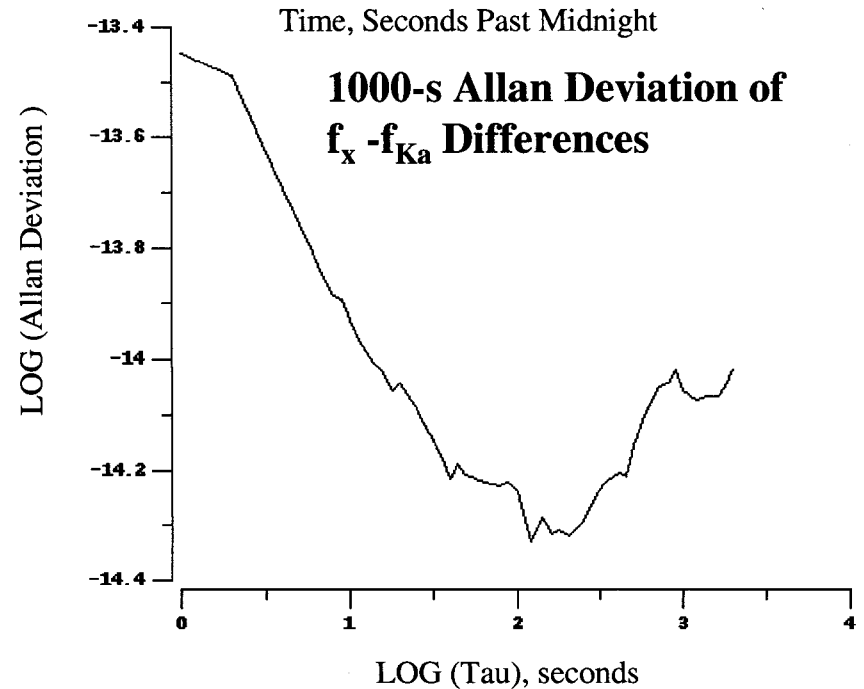
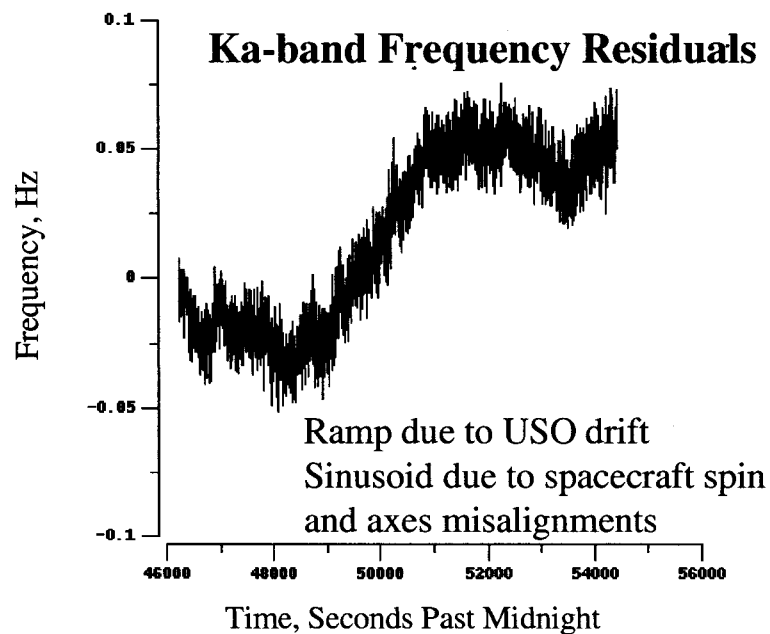
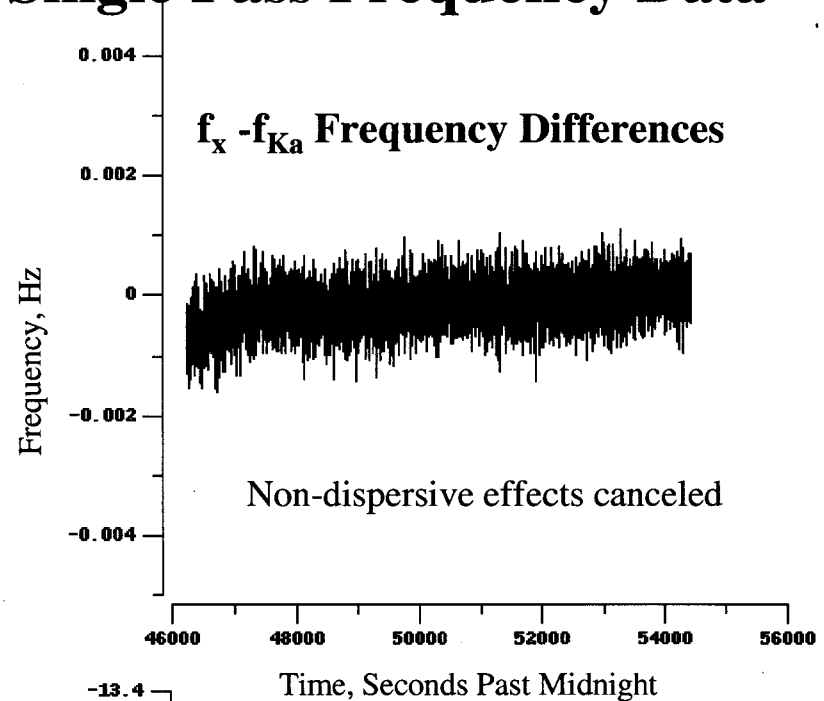
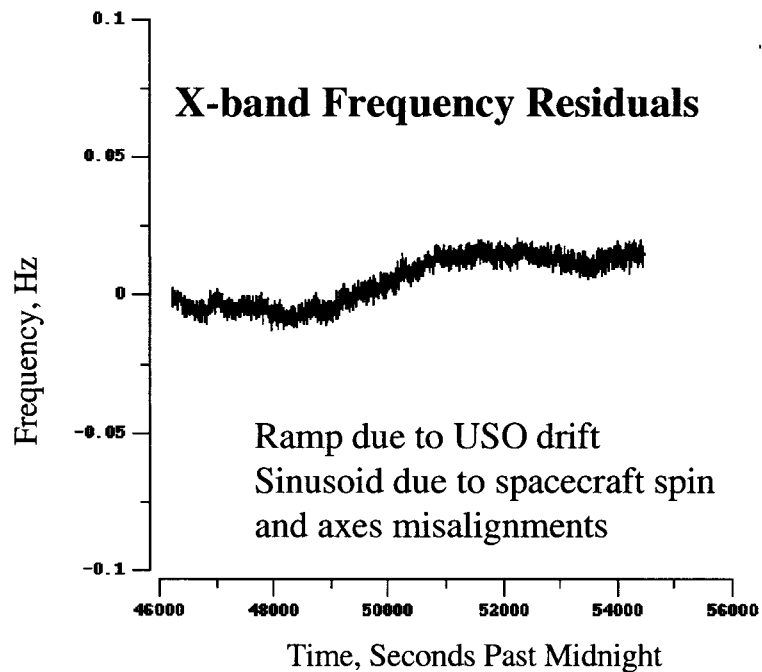
Coherent processing is used for the dual X/Ka frequency analysis and correlation.

# DSS 13 R&D Beam Waveguide (BWG) Antenna

- R&D 34-m BWG antenna was built as a prototype for the evolving DSN BWG subnet
- Subterranean pedestal room provides stable environment for feed, receiver and electronics development
- Provides easy access to multiple development stations at feed ring located in subterranean pedestal room
- Lower maintenance costs compared to non-BWG antennas
- Performance is less susceptible to weather, for example, lower attenuation during rain



# January 17, 1997 Example of Single Pass Frequency Data

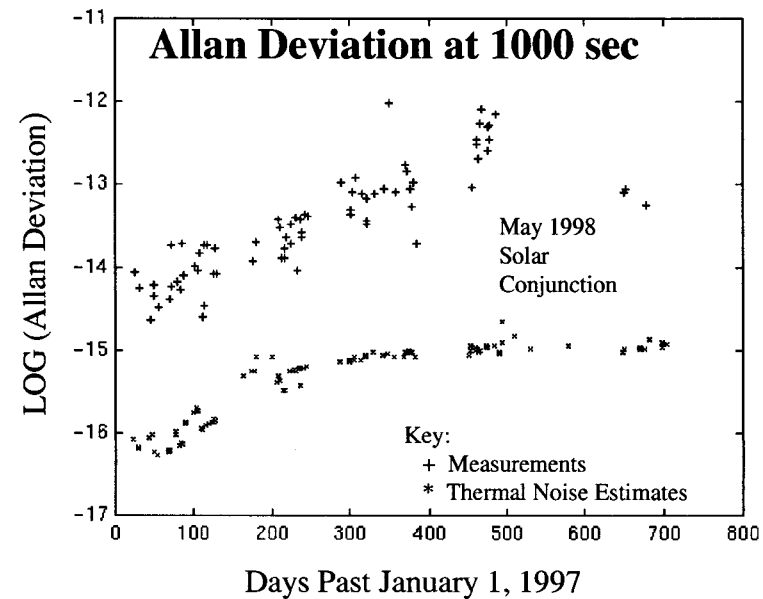
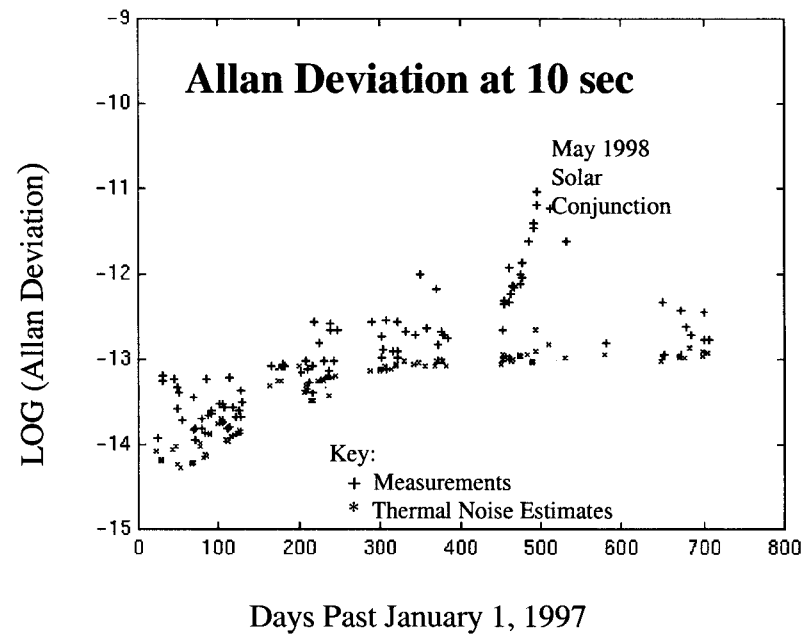
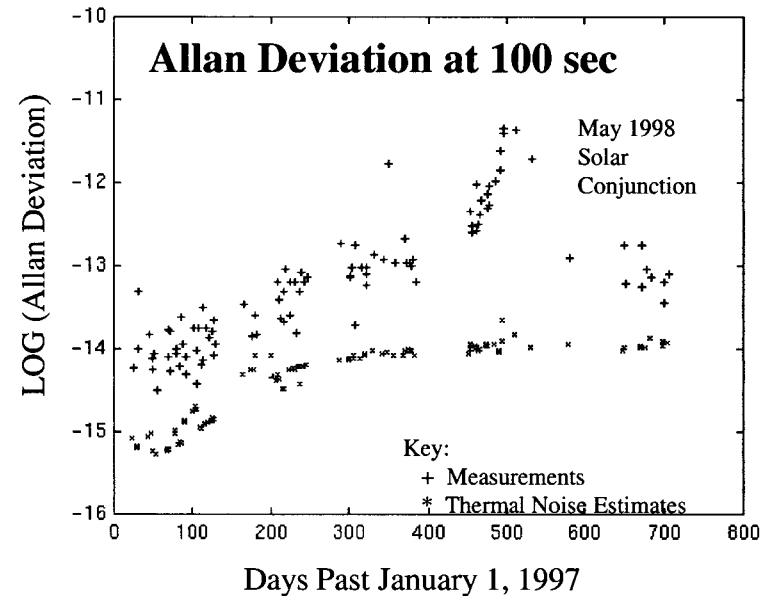
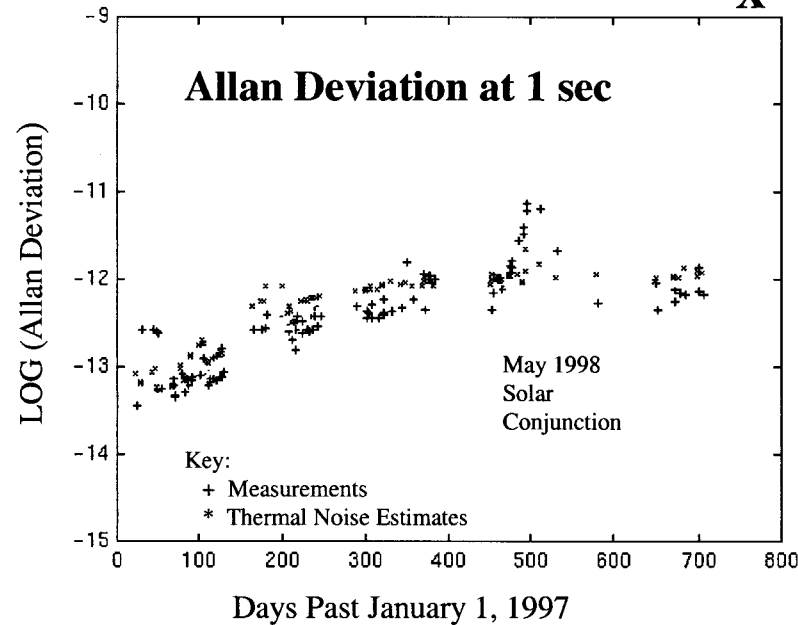


# Single Band Allan Deviation Summary

- X-band and Ka-band Allan deviations agree when thermal noise does not dominate
- In cases where thermal noise dominates, Allan deviation measurements agree with thermal noise estimates derived from measured carrier-to-noise ratios (CNR's)
- When CNR is sufficiently high,
  - Allan deviation measurements are consistent with expected levels due to USO, troposphere, or unmodeled spacecraft motion

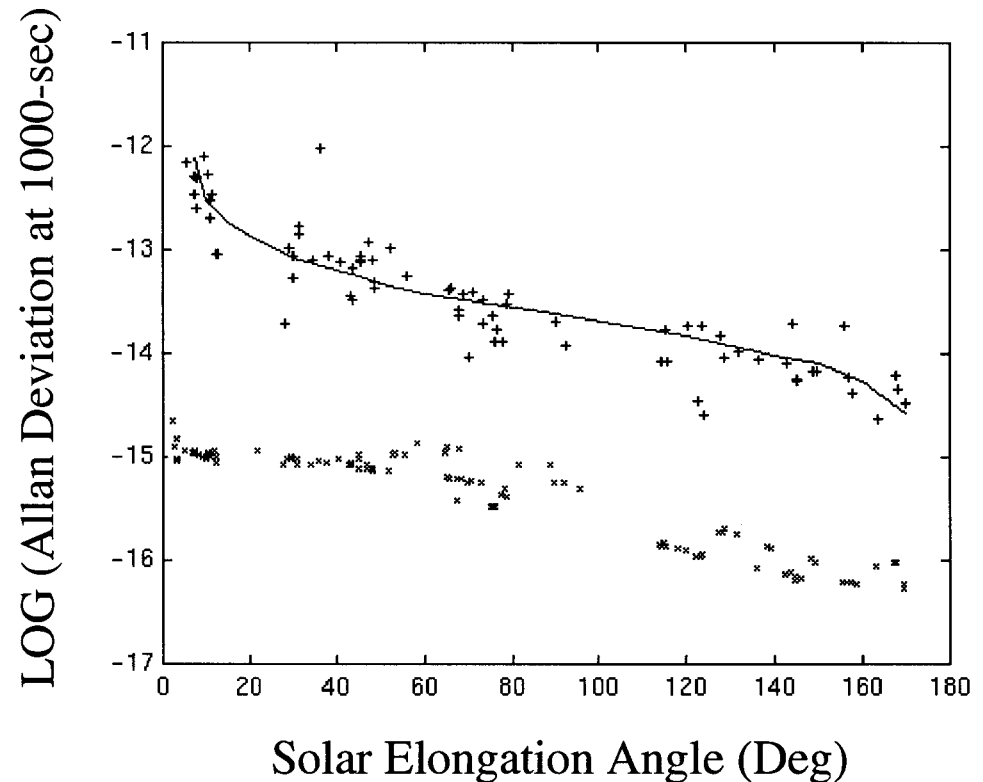
Allan Deviation Example for pass January 17, 1997			
tau (sec)	X-band	Ka-band	Dominating Noise Contributions
1	$1.15 \times 10^{-13}$	$1.11 \times 10^{-13}$	USO/Media
10	$1.01 \times 10^{-13}$	$1.00 \times 10^{-13}$	USO/Media
100	$0.96 \times 10^{-13}$	$0.97 \times 10^{-13}$	USO/Media
1000	$3.91 \times 10^{-13}$	$3.93 \times 10^{-13}$	Unmodeled spacecraft motion

# Allan Deviation of $f_X - f_{Ka}/3.8$ Frequency Differences



# Allan Deviation of $(f_x - f_{Ka}/3.8)$ versus Solar Elongation Angle

- Non-Dispersive noise sources cancel in frequency difference (dynamic spacecraft motion, neutral atmosphere, frequency standards, etc.)
- Remaining noise sources are thermal noise and charged particles
  - Thermal noise dominates at short time scales
  - Charged particles dominate at high time scales
- Difference frequency is a measure of the charged particle effect on the X-band link
- 1000-s Allan deviation decreases with increasing SEP angle consistent with expected charged particle signature
- 1000-s Allan deviation of  $6 \times 10^{-15}$  is in agreement with predicted value in anti-solar direction



Symbol Key -

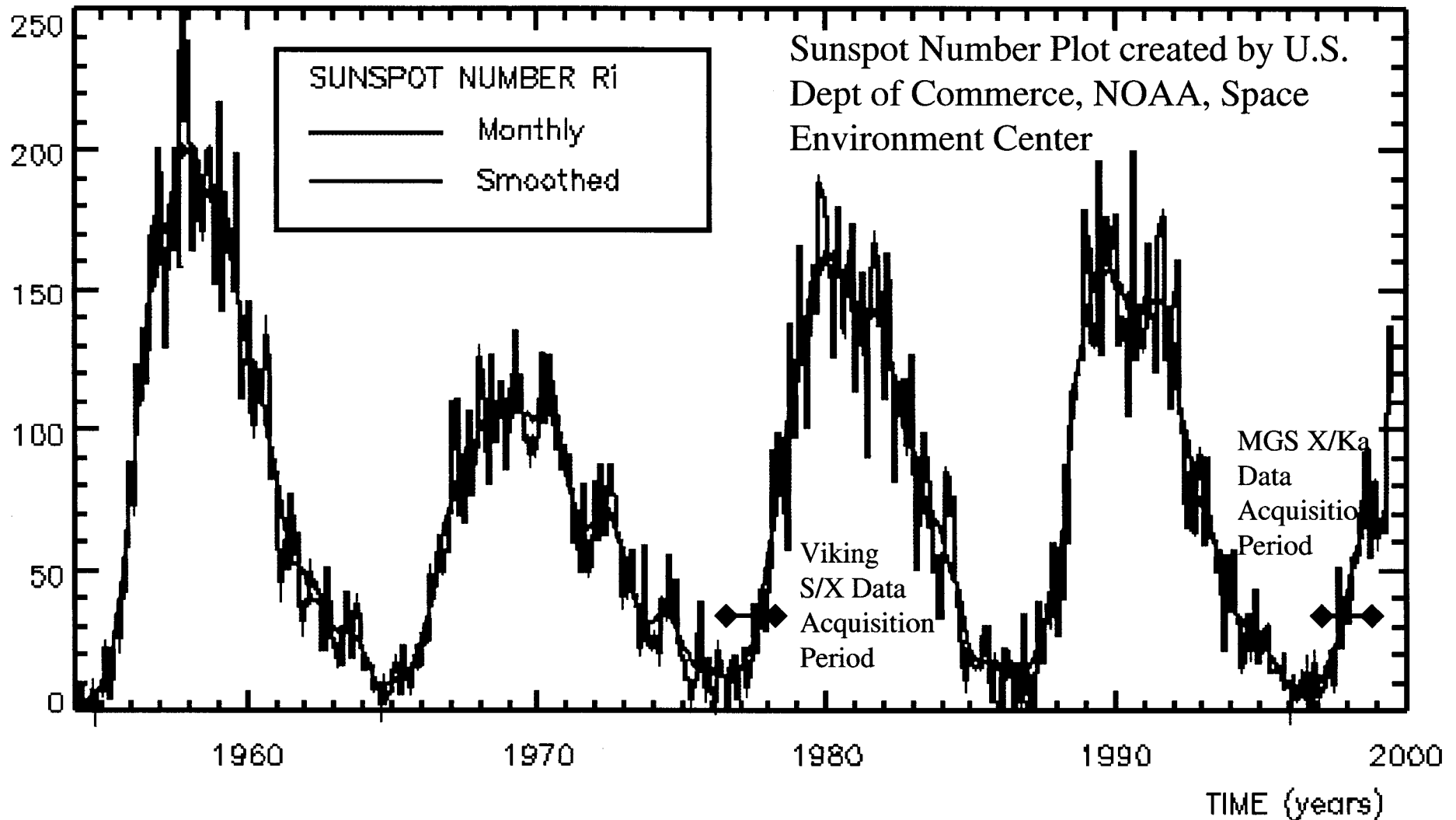
+ Allan Deviation Measurements at 1000-s of

$f_x - f_{Ka}/3.8$  frequency difference

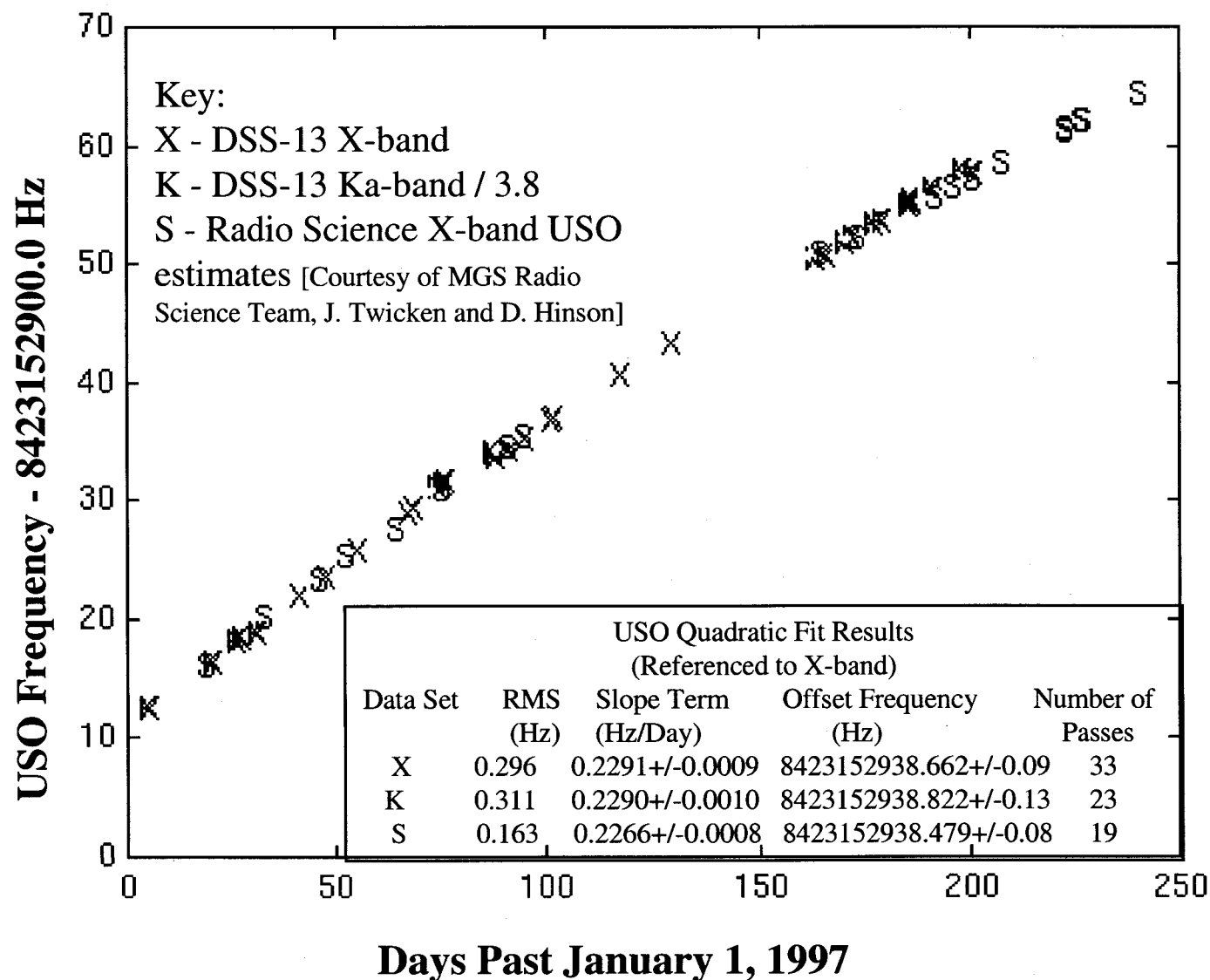
\* Estimates of Thermal Noise using Pc/No

Solid curve - Armstrong et. al. 1979 Viking S-band/X-band data acquired between 1976.3 to 1978.3 (scaled appropriately)

# MGS X/Ka and Viking S/X Data Acquisition Periods and Sunspot Number

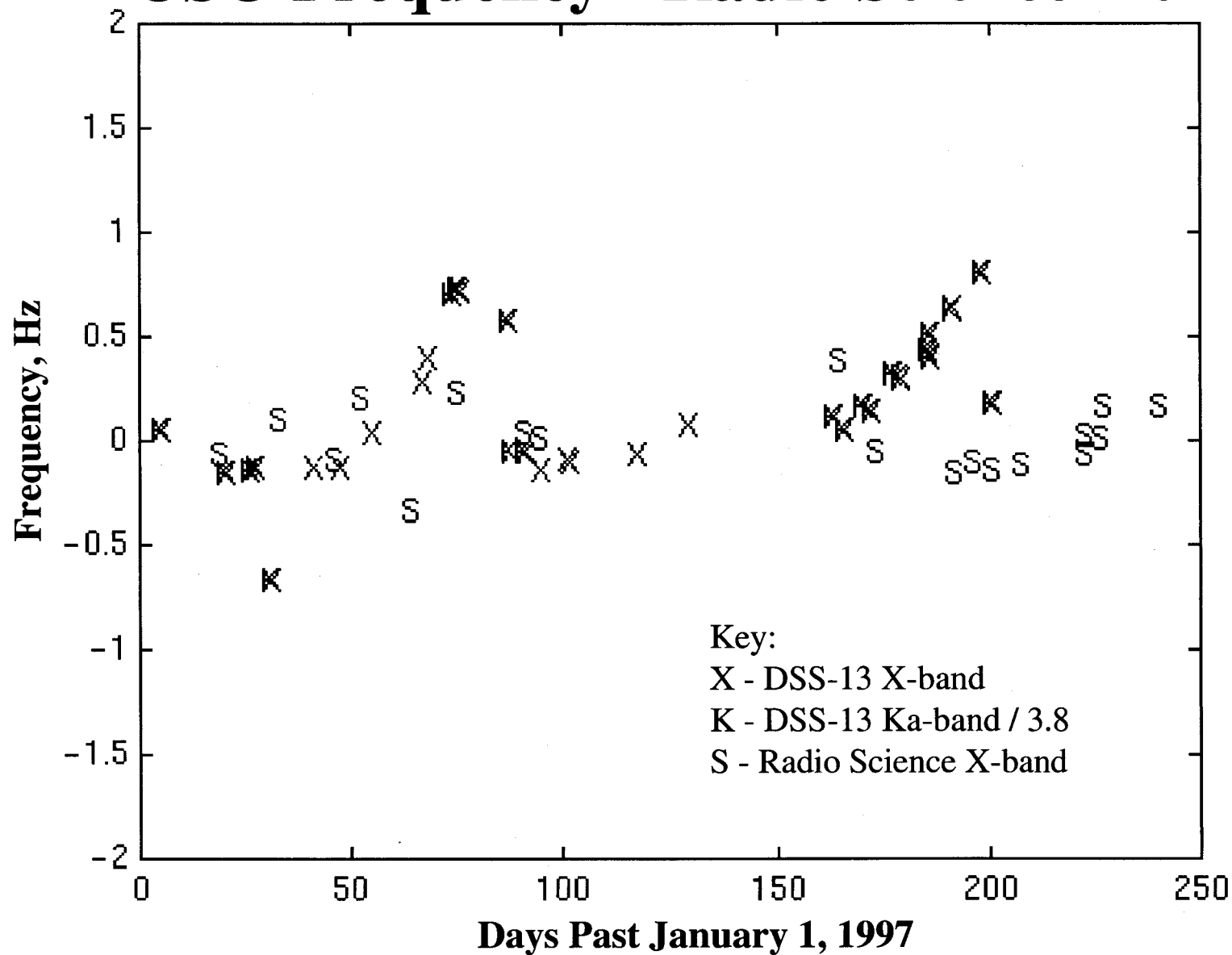


# Mars Global Surveyor USO Frequency



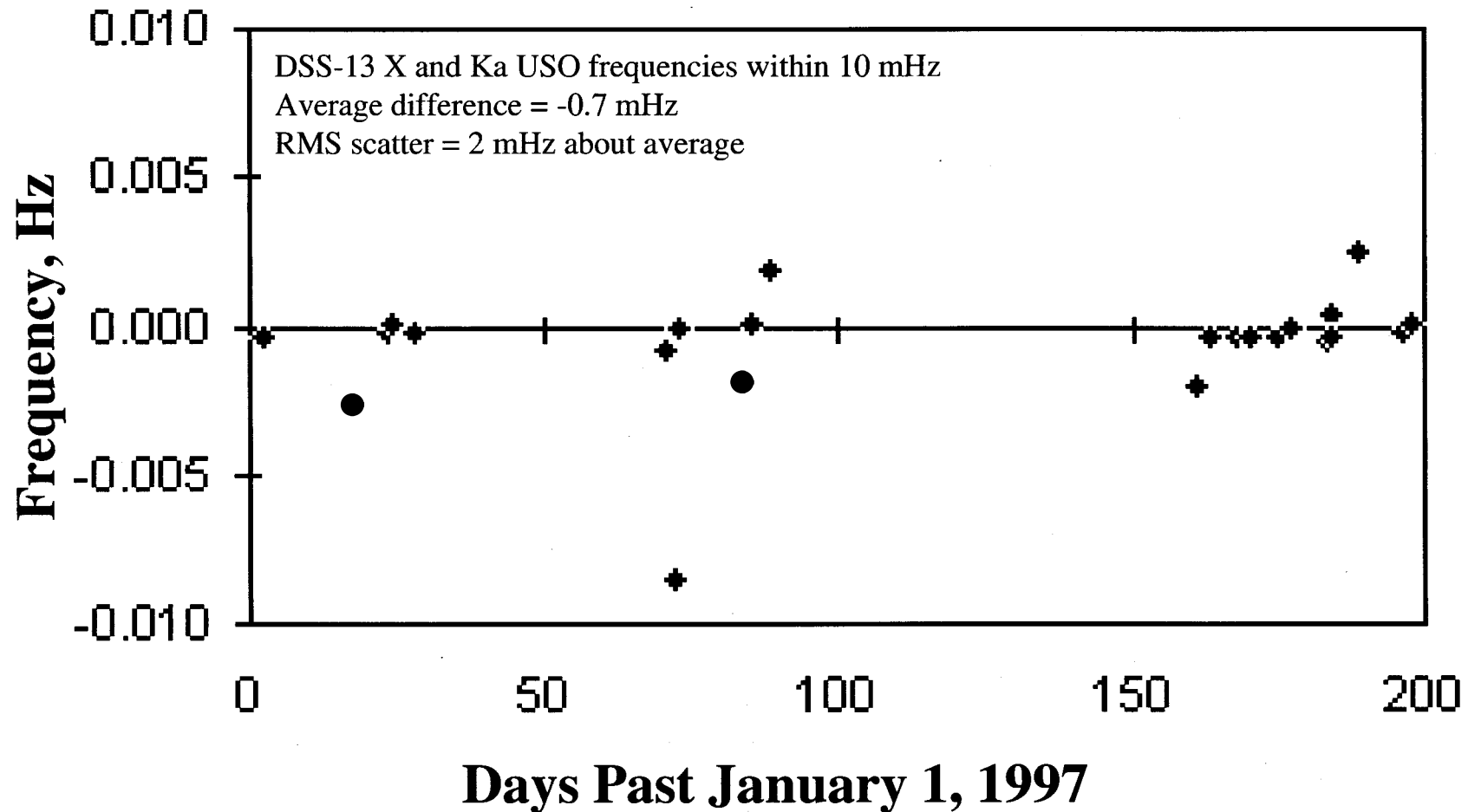
# Mars Global Surveyor

## USO Frequency - Radio Science Fit



# Mars Global Surveyor

## Difference of DSS-13 X-band and Ka-band USO Frequencies



# CONCLUSIONS

- The MGS/KaBLE-II link experiment measured frequency residuals which were in agreement between bands and whose statistics were consistent with expected noise sources.
- The measured 1000-s Allan deviation of the difference data type and its signature with solar elongation angle were shown to be consistent with expected levels at X-band due to charged particles.
- The DSS-13 X-band and Ka-band USO frequencies estimated from common time periods agreed between bands to better than 10 mHz, and these estimates agreed with independent MGS Radio Science estimates to better than 1 Hz.